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HEAT SETTING PROCEDURES FOR HELICAL COILED SPRINGS

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FINAL REPORT

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RESEARCH DIRECTORATE

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Various heat setting procedures for the manufacture of helical compression springs were investigated to determine optimum heat setting methods that will minimize operational spring set and load losses. Production springs were fabricated from music wire, stainless steel and chrome vanadium materials. The springs were given heat setting treatments under different conditions of temperatures, time durations and stress levels. Effects of the various heat setting procedures on spring set and load reductions were evaluated by laboratory

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endurance tests. Recommended heat setting procedures based on study results are given for the spring materials and test conditions investigated in this project.

Contents

OBJECTIVES

The objectives of this program were to evaluate various heat setting procedures and to determine the most beneficial procedures to minimize operational set and load losses of helical compression springs.

INTRODUCTION

The advantages of presetting (also called cold setting or scragging) of springs have been recognized for some time. This operation induces beneficial residual stresses within the spring material which increases its elastic limit and load capacity. This procedure consists of coiling the spring to a length somewhat greater than the free length desired and then compressing the spring beyond the elastic limit. Figure 1 in the Appendix shows a typical load deflection diagram thus obtained.[1] Point P_1 represents the initial elastic limit and P_2 the maximum load during the operation. On unloading the spring, the load drops along the dashed curve which is essentially a straight line and some set occurs. On reloading, the resultant elastic limit is raised to point P_2 which is considerably higher than the original value P_1. Presetting is a strain hardening operation that allows the use of higher design stresses, but it also adds another step to the manufacturing process.

Similar to presetting of springs, heat setting also induces favorable residual stresses within the wire material; however, the stress pattern produced is deeper and more permanent, and thus will provide springs that are more resistant to setting. Heat setting differs from presetting in that the springs are compressed on fixtures to a specified stress level and then subjected to a prescribed temperature while compressed for the required time. A spring so treated will take some permanent set depending on the severity of the stress level and temperature used in the heat setting operation. However, if the spring design and the heat setting procedure are correct, the completed spring will meet the desired specifications and will not take appreciable set in subsequent service. In this study, relatively low heat setting temperatures were applied because the subsequent evaluation endurance tests were conducted at ambient temperatures.

DISCUSSION

A. Material and Heat Setting Treatments

The helical compression springs that were used in this program were fabricated from the following spring tempered materials and given the specified stress relieving treatments.

[1]Wahl, A.M., Mechanical Springs, McGraw-Hill Book Company, Inc., New York, New York, 1963.

1) Music Wire, QQ-W-470
Wire diameter = 0.043 inch
Stress relieve: Heat at 450° ± 10° for 30 minutes

2) Stainless Steel, QQ-W-423, Comp. FS302
Wire diameter = 0.043 inch
Stress relieve: Heat at 800° F ± 25° for 30 minutes

3) Chrome Vanadium, QQ-W-412, Comp. 1
Wire diameter = 0.043 inch
Stress relieve: Heat at 700° F ± 20° for 30 minutes

One basic spring design was used in this program; detail specifications for this design are given in the Appendix. One hundred and thirty springs were fabricated from each material and stress relieved in accordance with the above instructions. Each group of one hundred and thirty springs were divided into thirteen sets of ten springs each and given the following heat setting procedures.

Springs compressed to a stress level of 100,000 psi

Set No.	Temperature(°F)	Time at temperature(min.)
1	200	30
2	200	60
3	300	30
4	300	60
5	400	30
6	400	60

Springs compressed to a stress level of 150,000 psi

Set No.	Temperature(°F)	Time at temperature(min.)
7	200	30
8	200	60
9	300	30
10	300	60
11	400	30
12	400	60
13	Controlled set - no heat setting applied	

The springs were compressed on suitable fixtures to the prescribed stress levels and then secured at that compressed height. They were then subjected to the specified temperature for the required time period. The above stress values are uncorrected and correspond to the following compressed spring heights.

For music wire and chrome vanadium materials
a) 100,000 psi corresponds to 1.580 inches
b) 150,000 psi corresponds to 1.020 inches

For stainless steel material
a) 100,000 psi corresponds to 1.470 inches
b) 150,000 psi corresponds to .860 inches

It was required that all wire material used in this program be free from surface irregularities. Prior to coiling, the material was examined thoroughly with the aid of a microscope. No cracks or surface defects were observed and the material was accepted for winding springs.

B. Test Procedures and Results

Test fixtures were designed and fabricated to endurance test the springs on the Krouse spring tester. A photograph of a heat set spring assembled onto the tester is shown in Figure 5 in the Appendix. Some experimentation in the endurance testing was necessary in order to establish the proper test conditions for the working stress levels and cyclic frequency which would produce spring set with the minimum amount of spring breakage. It was determined that the music wire springs should be cycled between the heights of 2.500 and 1.000 inches which corresponds to stress levels of 18,000 psi and 152,000 psi respectively; and at a frequency of 1275 cycles per minute. Springs were cycled for a total of 50,000 compressions with measurements taken of the free heights and spring loads periodically during the test.

Load at 2.500 inches and free height measurements taken on the individual music wire springs before and after 50,000 compression cycles are shown in tables 1 to 6 in the Appendix. Test results of only four springs are given for set 1 because six springs from this set were expended to establish the stress and frequency test conditions. Fewer than 10 springs are also listed in some of the other sets, due to spring breakage that occurred before the completion of 50,000 cycles.

The stainless steel springs were endurance tested between the heights of 2.200 and 1.000 inches which corresponds to stress levels of 41,000 psi and 139,000 psi respectively; and at a rate of 1000 cycles per minute. Three springs each from sets 2 and 6 were used to establish the test conditions. Measured free height and load measurements taken on the springs before and after cycling are shown in tables 7 to 12. Five springs each from sets 9 and 10 were tested since this sample was considered sufficient to provide adequate data to assess spring characteristics.

The chrome vanadium springs were endurance tested under the same conditions as were the music wire springs. Test data for the chrome vanadium springs are given in tables 13 to 17.

The criteria used in measuring the amount of spring set are the load at a particular compressed height and the change in free height. The spring load (at 2.500 inches) is considered a more practical and meaningful method to measure set for this project. Some of the heat setting procedures that were used proved to be too severe for the spring material and produced an excessive set. In some cases, the resultant free height after the heat setting operation was less than 2.500 inches; this occurred with the heat setting procedures that were performed at a stress level of 150,000 psi and at the maximum temperature. Excessive set as a result of the heat setting treatment occurred to sets 11 and 12 of the music wire and stainless steel springs as well as to sets 9 to 12 of the chrome vanadium springs. Consequently, these sets were not endurance tested because the free heights were slightly above or below the 2.500 value.

The average load values before and after 50,000 cycles of each set of music wire springs are shown in figure 2 in the Appendix. For each set, the left bar column represents the average load before the endurance test and the right bar column indicates the average value after the 50,000 compressions. Similarly, the average load values for the stainless steel and chrome vanadium spring sets are depicted in figures 3 and 4 respectively.

CONCLUSIONS

A review of figure 2 shows that the heat setting procedure that is most effective for music wire springs to minimize load loss due to operational set is the procedure that was applied to set 1 (i.e. stress level = 100,000 psi, temperature = 200°F and time = 30 minutes.) The final load after testing for set 1 is twice as large as the final load for the untreated set 13. The heat setting procedures that were given to sets 2 and 7 were almost equally beneficial since these springs sustained a high load level.

Figure 3 shows that all the heat setting treatments that were performed at a stress level of 100,000 psi aided to increase the durability of the stainless steel springs. However, the treatments that were applied to sets 1 and 4 provided the best results.

The benefit derived from heat setting by the chrome vanadium springs is rather minimal as can be observed from figure 4. The heat setting procedure that is related to set 1 induced the most favorable strength properties.

Load retention property of music wire springs is benefitted more by heat setting than those of stainless steel or chrome vanadium springs.

Generally, the difference in heating times of 30 minutes and 60 minutes had little effect on spring load durability.

Test results show that of the three temperature values that were used in this study, the temperature of 200°F produced the most favorable results. However, it is possible that a somewhat lower temperature may produce an even higher resistance to spring set. Limitations on funds and material precluded the evaluation of other temperature varibles.

RECOMMENDATIONS

1. The heat setting procedure of

   Stress level = 100,000 psi
   Temperature = 200°F
   Time at temperature = 30 minutes

   should be applied to the following materials and operating conditions:

   <u>Music wire and chrome vanadium materials</u>
   Wire size approximately .043 inch
   Stress range of 18,000 psi to 152,000 psi
   Loading frequency 1275 cycles per minute

   <u>Stainless steel material</u>
   Wire size approximately .043
   Stress range 41,000 psi to 130,000 psi
   Loading frequency 1000 cycles per minute

2. Temperatures in the range of 100°F to 200°F should be investigated if a further study on heat setting procedure is conducted.

Appendix

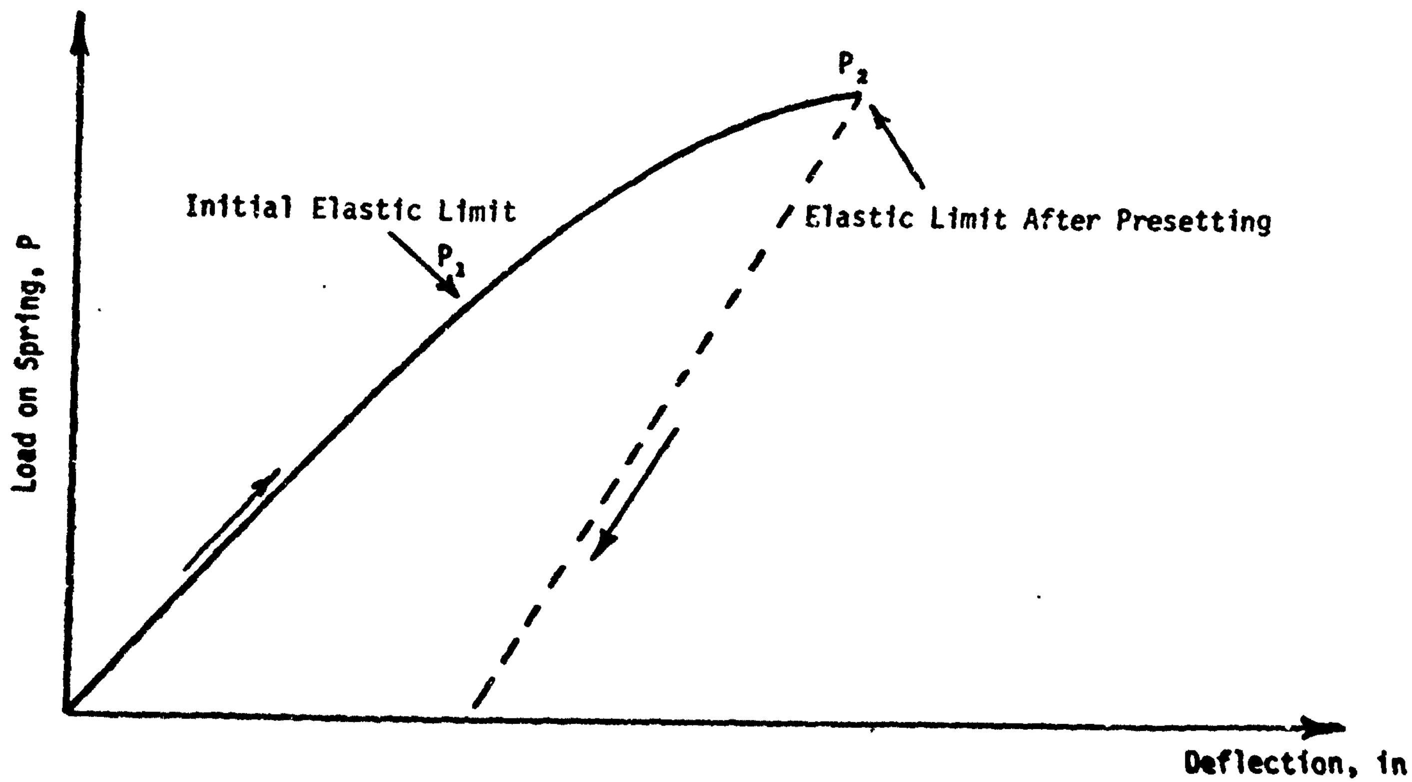

FIGURE 1

Typical Load Deflection Diagram of Spring During Presetting

SPECIFICATIONS

HEAT SET SPRING

WIRE SIZE (IN.)	.043
OUTSIDE DIAMETER (IN.)	.370 ±.005
TOTAL COILS	18.5
TYPE OF ENDS	CLOSED AND GROUND
FREE HEIGHT, APPROX. (IN.)	2.70
MEAN ASSEMBLED HEIGHT (IN.)	2.500
LOAD AT MEAN ASSEMBLED HEIGHT (LB.)	2.0 REF.
MINIMUM OPERATION HEIGHT (IN.)	1.000
LOAD-DEFLECTION RATE (LB./IN.)	8.5
MAXIMUM SOLID HEIGHT (IN.)	.830
SPRING HELIX	L.H.

Table 1

Music Wire Springs

Set 1 - Heat Set; Stress = 100,000 psi;
Temperature = 200°F; Time = 30 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.5	2.4	2.786	2.738
Spring 2	2.7	2.3	2.804	2.726
Spring 3	2.5	2.0	2.756	2.690
Spring 4	2.6	2.1	2.752	2.712
Average	2.58	2.20	2.774	2.716

Set 2 - Heat Set; Stress = 100,000 psi;
Temperature = 200°F; Time = 60 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.5	2.4	2.764	2.721
Spring 2	2.5	2.0	2.768	2.700
Spring 3	2.6	2.2	2.784	2.743
Spring 4	2.6	2.4	2.764	2.720
Spring 5	2.5	2.0	2.766	2.704
Spring 6	2.7	2.0	2.807	2.702
Spring 7	2.6	2.1	2.784	2.716
Spring 8	2.5	2.1	2.754	2.714
Spring 9	2.6	2.2	2.807	2.743
Spring 10	2.5	2.0	2.783	2.723
Average	2.56	2.14	2.778	2.719

Table 2

Music Wire Springs

Set 3 - Heat Set; Stress = 100,000 psi; Temperature = 300°F; Time = 30 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.5	1.2	2.743	2.604
Spring 2	2.4	1.0	2.753	2.606
Spring 3	2.6	2.0	2.804	2.706
Spring 4	2.3	2.0	2.764	2.708
Spring 5	2.4	1.4	2.753	2.652
Spring 6	2.5	1.7	2.764	2.703
Spring 7	2.6	1.3	2.804	2.609
Spring 8	2.4	0.9	2.766	2.546
Average	2.46	1.44	2.769	2.642

Set 4 - Heat Set; Stress = 100,000 psi; Temperature = 300°F; Time = 60 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.4	1.5	2.758	2.663
Spring 2	2.5	1.6	2.749	2.701
Spring 3	2.5	1.5	2.766	2.653
Spring 4	2.3	1.7	2.743	2.683
Spring 5	2.5	1.2	2.767	2.655
Spring 6	2.4	1.7	2.746	2.684
Spring 7	2.5	2.0	2.748	2.705
Spring 8	2.5	1.6	2.744	2.709
Average	2.45	1.60	2.753	2.682

Table 3

Music Wire Springs

Set 5 - Heat Set; Stress = 100,000 psi;
Temperature = 400°F; Time = 30 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.9	0.5	2.708	2.589
Spring 2	2.1	0.5	2.715	2.569
Spring 3	2.0	1.2	2.712	2.616
Spring 4	1.8	1.0	2.706	2.604
Spring 5	2.0	1.0	2.708	2.618
Spring 6	2.0	1.4	2.724	2.660
Spring 7	1.8	1.0	2.695	2.603
Average	1.94	0.94	2.710	2.608

Set 6 - Heat Set; Stress = 100,000 psi;
Temperature = 400°F; Time = 60 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.0	0.7	2.640	2.575
Spring 2	1.2	0.7	2.627	2.552
Spring 3	1.2	0.5	2.603	2.501
Spring 4	1.0	0.9	2.610	2.570
Spring 5	1.5	1.0	2.600	2.578
Spring 6	1.5	0.5	2.614	2.528
Spring 7	1.5	0.6	2.625	2.560
Average	1.27	0.70	2.617	2.552

Table 4

Music Wire Springs

Set 7 - Heat Set; Stress = 150,000 psi;
Temperature = 200°F; Time = 30 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.7	1.5	2.695	2.565
Spring 2	2.4	2.2	2.720	2.715
Spring 3	2.4	2.2	2.732	2.725
Spring 4	2.4	1.5	2.727	2.625
Spring 5	2.4	2.4	2.716	2.708
Spring 6	2.4	2.2	2.712	2.690
Spring 7	2.4	2.2	2.728	2.717
Spring 8	2.2	2.2	2.706	2.706
Spring 9	2.4	2.2	2.741	2.723
Spring 10	2.2	2.0	2.702	2.680
Average	2.29	2.06	2.718	2.685

Set 8 - Heat Set; Stress = 150,000 psi;
Temperature = 200°F; Time = 60 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	2.0	1.5	2.757	2.652
Spring 2	2.1	1.2	2.704	2.580
Spring 3	2.0	1.0	2.687	2.585
Spring 4	2.2	1.2	2.713	2.610
Spring 5	2.0	1.0	2.715	2.600
Spring 6	2.1	1.5	2.708	2.640
Spring 7	2.0	0.8	2.695	2.542
Spring 8	2.0	0.6	2.701	2.538
Average	2.05	1.10	2.710	2.593

Table 5

Music Wire Springs

Set 9 - Heat Set; Stress = 150,000 psi;
Temperature = 300°F; Time = 30min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.6	1.5	2.665	2.660
Spring 2	1.6	1.5	2.663	2.645
Spring 3	1.5	1.4	2.667	2.645
Spring 4	1.4	0.5	2.641	2.563
Spring 5	1.5	1.4	2.663	2.642
Spring 6	1.6	1.0	2.651	2.611
Spring 7	1.5	1.0	2.644	2.603
Spring 8	1.5	1.1	2.646	2.602
Spring 9	1.5	1.4	2.648	2.632
Spring 10	1.6	1.4	2.652	2.628
Average	1.53	1.22	2.654	2.623

Set 10 - Heat Set; Stress = 150,000 psi;
Temperature = 300°F; Time = 60 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.0	0.5	2.600	2.540
Spring 2	1.0	0.9	2.612	2.575
Spring 3	1.1	0.6	2.605	2.545
Spring 4	1.2	0.7	2.583	2.567
Spring 5	1.0	0.9	2.608	2.575
Spring 6	1.1	1.0	2.615	2.595
Spring 7	1.2	1.0	2.606	2.597
Spring 8	1.0	0.0	2.578	2.425
Spring 9	1.0	0.5	2.602	2.525
Average	1.07	.68	2.601	2.549

Table 6

Music Wire Springs

Set 13 - Controlled Set; No heat setting applied

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	3.0	1.0	2.788	2.603
Spring 2	2.9	1.0	2.772	2.615
Spring 3	2.9	1.3	2.783	2.675
Spring 4	3.0	1.4	2.785	2.700
Spring 5	2.9	1.1	2.790	2.595
Spring 6	2.8	0.9	2.775	2.590
Spring 7	3.0	0.5	2.788	2.557
Spring 8	3.1	1.0	2.795	2.595
Average	2.95	1.02	2.785	2.616

Table 7

Stainless Steel Springs

Set 1 - Heat Set; Stress = 100,000 psi;
Temperature = 200°F; Time = 30 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	2.2	2.2	2.740	2.720
Spring 2	2.3	2.2	2.745	2.740
Spring 3	2.2	2.2	2.750	2.735
Spring 4	2.5	2.2	2.745	2.740
Spring 5	2.2	2.0	2.730	2.715
Spring 6	2.2	1.7	2.740	2.655
Spring 7	2.3	2.2	2.755	2.737
Spring 8	2.2	2.0	2.755	2.645
Average	2.26	2.09	2.745	2.711

Set 2 - Heat Set; Stress = 100,000 psi;
Temperature = 200°F; Time = 60 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	2.2	1.8	2.775	2.640
Spring 2	2.2	2.0	2.735	2.725
Spring 3	2.3	2.0	2.745	2.720
Spring 4	2.2	2.0	2.740	2.723
Spring 5	2.4	2.1	2.747	2.688
Spring 6	2.4	2.0	2.737	2.725
Spring 7	2.2	1.9	2.725	2.693
Average	2.27	1.97	2.743	2.702

Table 8

Stainless Steel Springs

Set 3 - Heat Set; Stress = 100,000 psi;
Temperature = 300°F; Time = 30 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.2	1.9	2.728	2.695
Spring 2	2.4	2.1	2.745	2.705
Spring 3	2.3	2.0	2.740	2.715
Spring 4	2.3	2.1	2.747	2.726
Spring 5	2.4	1.9	2.742	2.690
Spring 6	2.2	2.0	2.702	2.695
Spring 7	2.2	2.0	2.720	2.708
Spring 8	2.4	1.8	2.735	2.660
Spring 9	2.2	2.0	2.725	2.711
Spring 10	2.2	2.1	2.737	2.710
Average	2.28	1.99	2.732	2.701

Set 4 - Heat Set; Stress = 100,000 psi;
Temperature = 300°F; Time 60 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.2	2.0	2.728	2.720
Spring 2	2.1	1.8	2.725	2.652
Spring 3	2.3	2.2	2.750	2.735
Spring 4	2.3	2.2	2.743	2.725
Spring 5	2.2	2.0	2.730	2.707
Spring 6	2.1	2.1	2.720	2.715
Spring 7	2.2	2.0	2.728	2.705
Spring 8	2.3	2.1	2.747	2.720
Spring 9	2.2	2.0	2.743	2.725
Average	2.21	2.04	2.745	2.712

Table 9

Stainless Steel Springs

Set 5 - Heat Set; Stress = 100,000 psi;
Temperature = 400°F; Time = 30 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.0	1.5	2.747	2.560
Spring 2	2.0	2.0	2.737	2.720
Spring 3	2.1	2.0	2.720	2.707
Spring 4	2.2	1.9	2.725	2.695
Spring 5	2.1	2.0	2.731	2.715
Spring 6	2.2	2.1	2.725	2.722
Spring 7	2.2	2.0	2.740	2.715
Spring 8	2.3	2.0	2.750	2.730
Spring 9	2.2	1.8	2.715	2.650
Average	2.14	1.92	2.732	2.690

Set 6 - Heat Set; Stress 100,000 psi;
Temperature = 400°F; Time = 60 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.2	2.2	2.735	2.725
Spring 2	2.2	1.7	2.728	2.650
Spring 3	2.1	1.5	2.720	2.612
Spring 4	2.2	2.2	2.737	2.715
Spring 5	2.0	2.0	2.745	2.717
Spring 6	2.0	2.0	2.732	2.715
Average	2.12	1.93	2.733	2.689

Table 10

Stainless Steel Springs

Set 7 - Heat Set; Stress = 150,000 psi; Temperature = 200°F; Time = 30 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	2.1	1.5	2.709	2.616
Spring 2	2.2	2.0	2.735	2.715
Spring 3	2.2	2.0	2.737	2.712
Spring 4	2.2	1.6	2.735	2.680
Spring 5	2.1	1.7	2.730	2.655
Spring 6	2.0	2.0	2.715	2.700
Spring 7	2.0	1.9	2.710	2.695
Average	2.11	1.81	2.724	2.682

Set 8 - Heat Set; Stress = 150,000 psi; Temperature = 200°F; Time 60 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	2.0	2.0	2.715	2.712
Spring 2	2.2	1.7	2.703	2.625
Spring 3	2.1	2.0	2.708	2.700
Spring 4	2.0	1.5	2.695	2.630
Spring 5	2.1	1.9	2.715	2.638
Spring 6	2.0	1.5	2.735	2.600
Spring 7	2.2	2.0	2.722	2.710
Spring 8	2.0	1.9	2.710	2.695
Spring 9	2.0	1.9	2.725	2.705
Spring 10	2.2	2.0	2.720	2.700
Average	2.08	1.84	2.715	2.672

Table 11

Stainless Steel Springs

Set 9 - Heat Set; Stress = 150,000 psi;
Temperature = 300°F; Time = 30 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.0	1.7	2.695	2.692
Spring 2	2.0	1.3	2.700	2.585
Spring 3	1.9	1.7	2.695	2.685
Spring 4	2.0	1.4	2.712	2.635
Spring 5	1.9	1.6	2.690	2.660
Average	1.96	1.54	2.699	2.651

Set 10 - Heat Set; Stress = 150,000 psi;
Temperature = 300°F; Time = 60 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	1.9	1.3	2.695	2.620
Spring 2	2.0	1.6	2.697	2.660
Spring 3	1.9	1.5	2.692	2.685
Spring 4	1.8	1.2	2.696	2.570
Spring 5	2.0	1.7	2.698	2.680
Average	1.92	1.46	2.696	2.643

Table 12

Stainless Steel Springs

Set 13 - Controlled Set; No heat setting applied

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	2.2	1.7	2.725	2.684
Spring 2	2.2	1.6	2.728	2.642
Spring 3	2.1	1.8	2.725	2.714
Spring 4	2.3	1.9	2.745	2.725
Spring 5	2.2	1.7	2.747	2.680
Spring 6	2.3	1.7	2.750	2.685
Spring 7	2.4	1.8	2.756	2.694
Spring 8	2.2	1.6	2.745	2.625
Average	2.24	1.72	2.740	2.681

Table 13

Chrome Vanadium Springs

Set 1 - Heat Set; Stress = 100,000 psi; Temperature = 200° F; Time = 30 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	1.7	1.5	2.675	2.652
Spring 2	1.5	1.5	2.658	2.625
Spring 3	1.7	1.6	2.657	2.625
Spring 4	2.0	1.5	2.656	2.635
Spring 5	1.7	1.7	2.655	2.640
Spring 6	1.5	1.5	2.657	2.645
Spring 7	1.7	1.6	2.662	2.655
Spring 8	1.8	1.6	2.660	2.650
Spring 9	1.7	1.7	2.645	2.645
Spring 10	1.7	1.7	2.650	2.644
Average	1.70	1.59	2.658	2.640

Set 2 - Heat Set; Stress = 100,000 psi; Temperature = 200°F; Time = 60 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	1.5	1.4	2.637	2.618
Spring 2	1.6	1.3	2.650	2.607
Spring 3	1.5	1.5	2.640	2.617
Spring 4	1.7	1.6	2.645	2.638
Spring 5	1.7	1.5	2.630	2.628
Spring 6	1.8	1.7	2.660	2.650
Spring 7	1.7	1.5	2.635	2.610
Spring 8	1.7	1.6	2.645	2.640
Spring 9	1.8	1.5	2.655	2.642
Spring 10	1.5	1.5	2.635	2.630
Average	1.65	1.51	2.643	2.628

Table 14

Chrome Vanadium Springs

Set 3 - Heat Set; Stress = 100,000 psi;
Temperature = 300°F; Time = 30 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	1.6	1.5	2.625	2.623
Spring 2	1.5	1.2	2.610	2.600
Spring 3	1.6	1.4	2.630	2.610
Spring 4	1.5	1.2	2.625	2.605
Spring 5	1.5	1.3	2.615	2.600
Spring 6	1.3	1.0	2.590	2.575
Spring 7	1.5	1.2	2.628	2.610
Spring 8	1.6	1.3	2.627	2.612
Spring 9	1.5	1.2	2.615	2.602
Spring 10	1.4	1.2	2.625	2.617
Average	1.50	1.25	2.619	2.605

Set 4 - Heat Set; Stress = 100,000 psi;
Temperature = 300°F; Time = 60 min.

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	1.4	1.2	2.595	2.585
Spring 2	1.5	1.4	2.610	2.603
Spring 3	1.5	1.4	2.620	2.613
Spring 4	1.6	1.2	2.625	2.608
Spring 5	1.5	1.5	2.631	2.625
Spring 6	1.6	1.4	2.636	2.610
Spring 7	1.5	1.4	2.612	2.605
Spring 8	1.6	1.5	2.625	2.616
Spring 9	1.5	1.4	2.613	2.608
Spring 10	1.5	1.2	2.632	2.606
Average	1.52	1.36	2.620	2.608

Table 15

Chrome Vanadium Springs

Set 5 - Heat Set; Stress = 100,000 psi; Temperature = 400°F; Time = 30 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.2	1.2	2.603	2.600
Spring 2	1.5	1.5	2.615	2.615
Spring 3	1.5	1.2	2.608	2.595
Spring 4	1.2	1.2	2.608	2.597
Spring 5	1.5	1.3	2.620	2.605
Spring 6	1.4	1.4	2.622	2.618
Spring 7	1.5	1.4	2.625	2.615
Spring 8	1.6	1.5	2.633	2.617
Spring 9	1.6	1.3	2.625	2.612
Spring 10	1.5	1.4	2.621	2.616
Average	1.45	1.34	2.618	2.609

Set 6 - Heat Set; Stress = 100,000 psi; Temperature = 400°F; Time = 60 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.5	1.0	2.632	2.508
Spring 2	1.5	1.0	2.625	2.590
Spring 3	1.6	1.2	2.611	2.595
Spring 4	1.5	1.5	2.630	2.625
Spring 5	1.5	1.5	2.627	2.620
Spring 6	1.6	1.4	2.622	2.605
Spring 7	1.5	1.2	2.612	2.610
Spring 8	1.5	1.4	2.608	2.600
Spring 9	1.5	1.4	2.616	2.615
Average	1.52	1.29	2.620	2.596

Table 16

Chrome Vanadium Springs

Set 7 - Heat Set; Stress = 150,000 psi; Temperature = 200°F; Time = 30 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.2	1.0	2.595	2.578
Spring 2	1.0	1.0	2.590	2.575
Spring 3	1.0	1.0	2.592	2.580
Spring 4	1.2	1.2	2.594	2.582
Spring 5	1.2	1.2	2.585	2.574
Spring 6	1.2	1.2	2.604	2.590
Spring 7	1.0	1.0	2.580	2.570
Spring 8	1.0	1.0	2.577	2.560
Spring 9	1.1	1.0	2.595	2.585
Spring 10	1.0	1.0	2.575	2.575
Average	1.09	1.06	2.589	2.577

Set 8 - Heat Set; Stress = 150,000 psi; Temperature = 200°F; Time = 60 min.

	Load at 2.500 inches (pounds) Before test	Load at 2.500 inches (pounds) After 50,000 cycles	Free height (inches) Before test	Free height (inches) After 50,000 cycles
Spring 1	1.2	0.9	2.652	2.567
Spring 2	1.1	1.0	2.584	2.565
Spring 3	0.9	0.7	2.565	2.545
Spring 4	1.0	0.9	2.575	2.562
Spring 5	0.9	0.7	2.565	2.555
Spring 6	1.0	0.9	2.580	2.562
Spring 7	1.0	0.9	2.570	2.568
Spring 8	1.1	1.0	2.583	2.570
Spring 9	1.0	0.9	2.572	2.555
Spring 10	1.0	1.0	2.565	2.560
Average	1.02	.89	2.581	2.561

Table 17

Chrome Vanadium Springs

Set 13 - Controlled Set; No heat setting applied

	Load at 2.500 inches (pounds)		Free height (inches)	
	Before test	After 50,000 cycles	Before test	After 50,000 cycles
Spring 1	2.0	1.1	2.680	2.596
Spring 2	2.0	1.5	2.675	2.650
Spring 3	1.7	1.3	2.657	2.615
Spring 4	2.0	1.4	2.695	2.630
Spring 5	1.9	1.4	2.675	2.634
Spring 6	2.0	1.4	2.678	2.633
Spring 7	1.7	1.1	2.655	2.580
Spring 8	1.9	1.5	2.665	2.645
Spring 9	2.0	1.4	2.682	2.630
Average	1.91	1.34	2.674	2.624

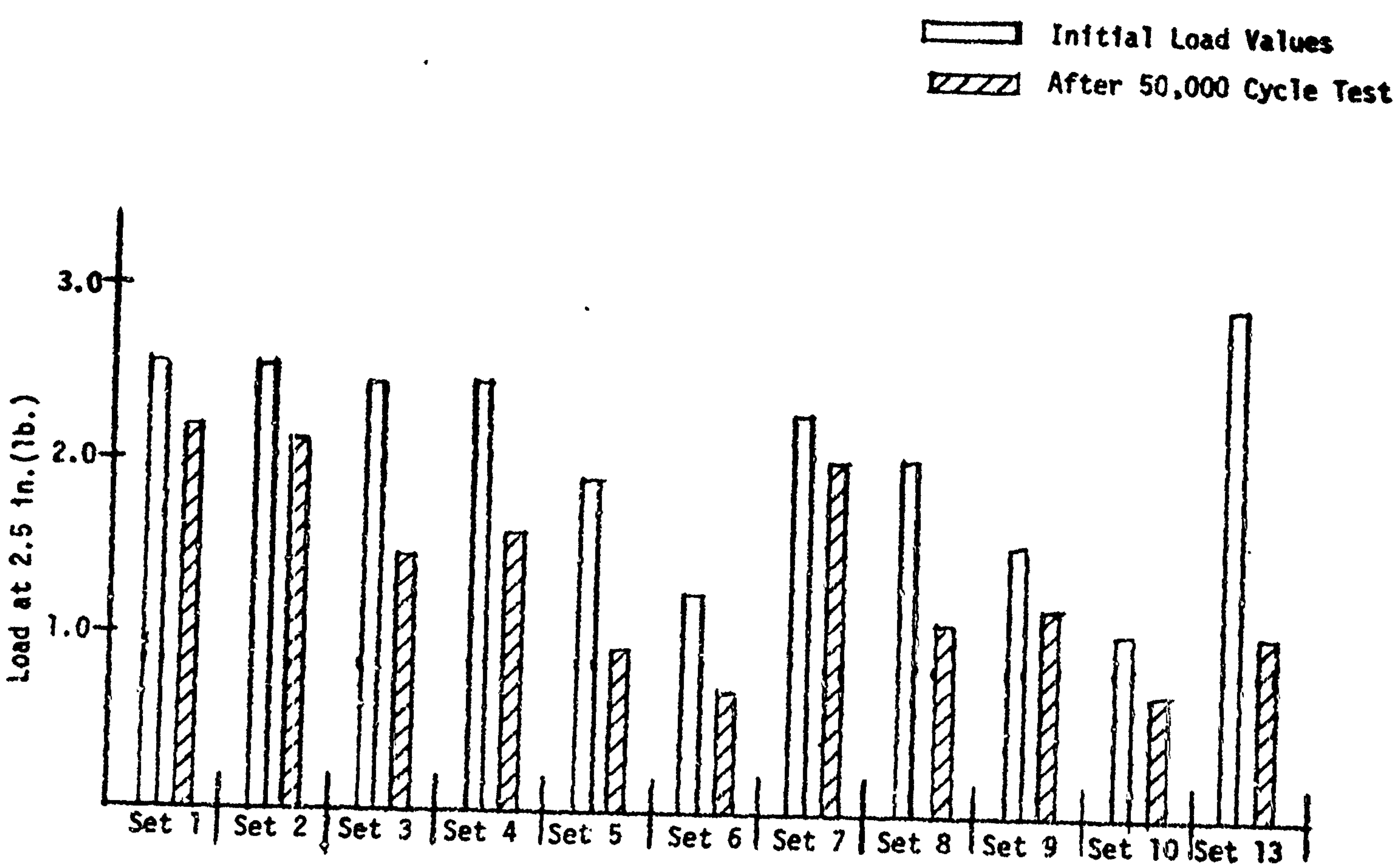

FIGURE 2

Music Wire Springs

Average Load Values Before and After 50,000 Cycle Test

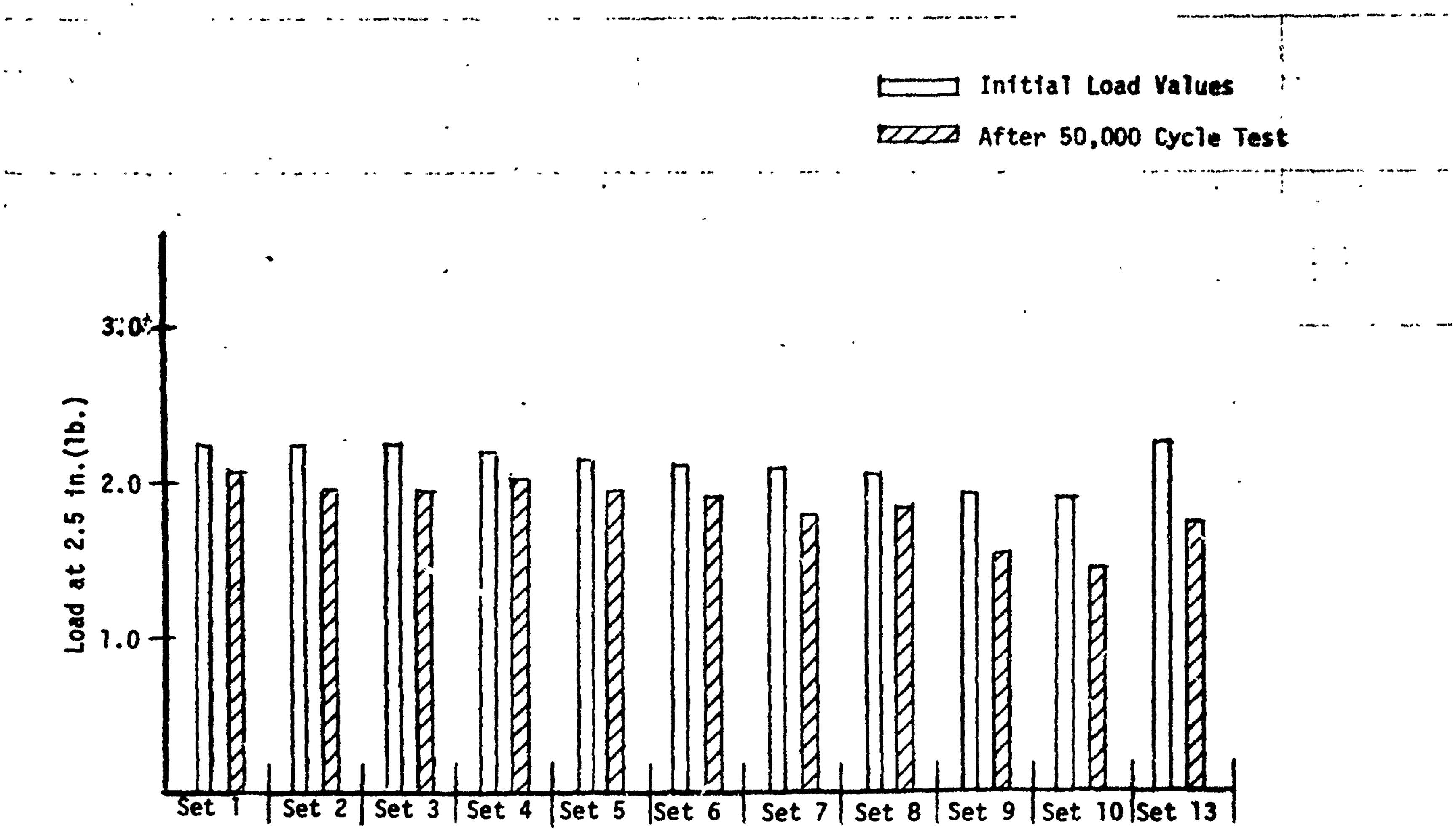

FIGURE 3
Stainless Steel Springs
Average Load Values Before and After 50,000 Cycle Test

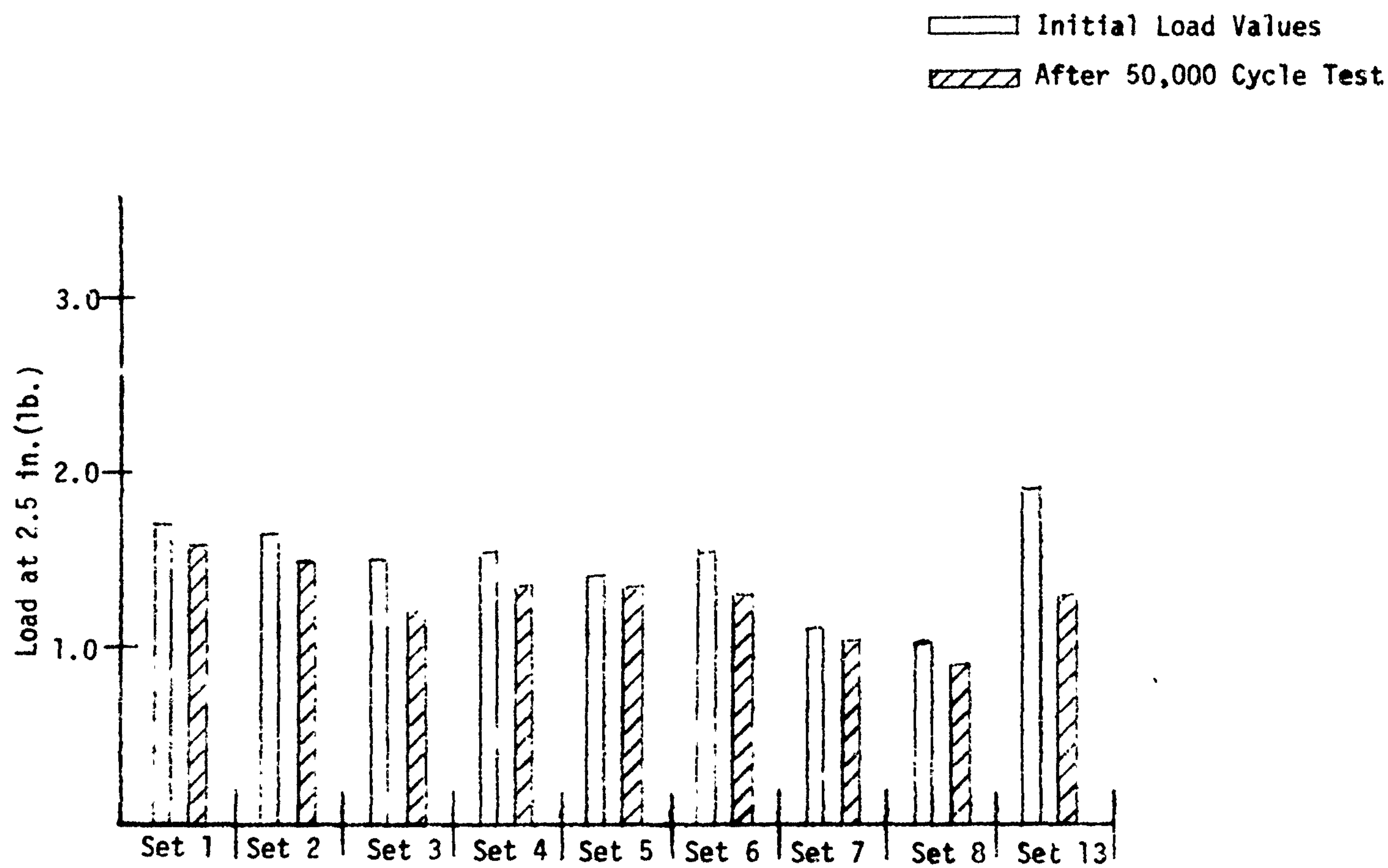

FIGURE 4

Chrome Vanadium Springs

Average Load Values Before and After 50,000 Cycle Test

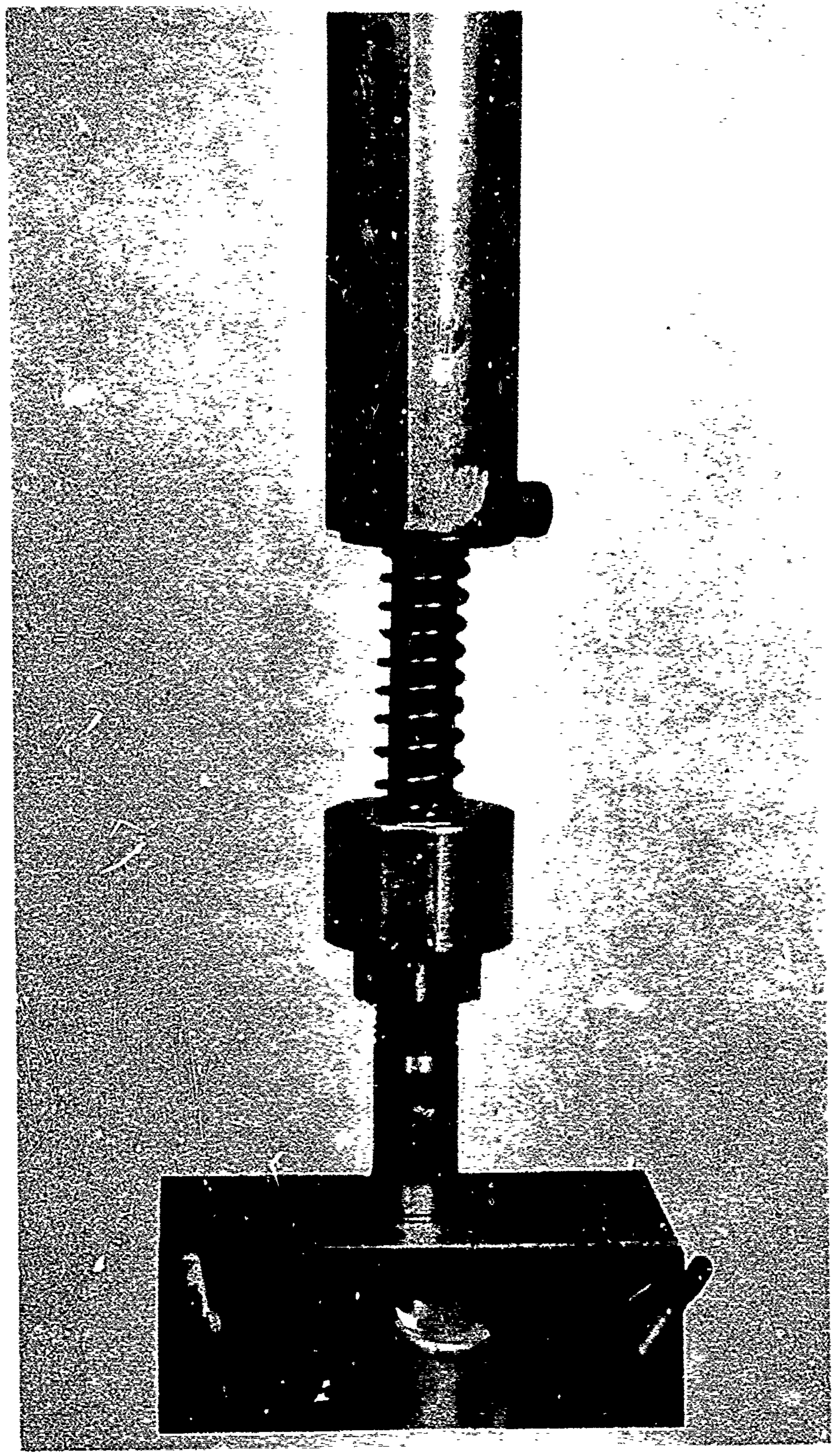

FIGURE 5

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HEAT SETTING PROCEDURES FOR HELICAL COILED SPRINGS

Prepared by: Henry P. Swieskowski

Technical Report No. R-TR-76-044, Dec 1976

29 pages, incl Figures & Tables

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